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Meteorological Analysis of the November 25 FIRE Cirrus-II Case: A Well-Defined Ridge-Crest Cirrus System over Oklahoma

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1 Introduction

On the morning of November 25 1991, a cirrus cloud system formed in a region extending eastward from the continental divide into central Oklahoma and southwestern Kansas (Figure 1). The system moved slowly eastward during the day and maintained a relatively constant scale and shape. From the satellite perspective, this cloud system had a number of morphological similarities to the 27-28 October FIRE Cirrus-I case analyzed by Starr and Wylie (1990). By comparison, the present case had much better rawinsonde coverage. The rawinsonde network was much more extensive and the cloud system was relatively slow moving and well-located with respect to the enhanced sounding network (Figure 2) and the NWS Wind Profiler Network.

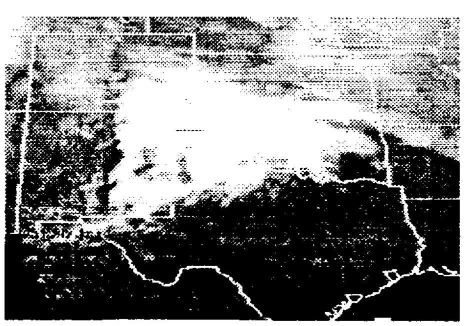

Figure 1: Infrared satellite imagery for 1200 UTC on 25 November 1991.

In addition to the rawinsonde soundings (1200 and 1800 UTC on 25 November and 0000 and 0600 UTC on 26 November) and satellite observations, four aircraft sorties were flown in the northern portion of this cirrus cloud system from mid-morning to mid-afternoon. These included microphysical-radiation profiling missions by the NCAR Sabreliner near Tulsa (about midway between COF and OUN in Figure 2) and the NCAR King Air near Ponca City (about 80 km upwind of Tulsa), a microphysical profiling mission by the UND Citation near Tulsa, and a NASA ER-2 overflight. Thus, very good data are available for this case although, unfortunately, the cloud system remained south of the FIRE Hub site at Coffeyville (COF) where extensive ground-based remote sensor were located. The northern edge of the cloud system was visible from COF during most of the day.

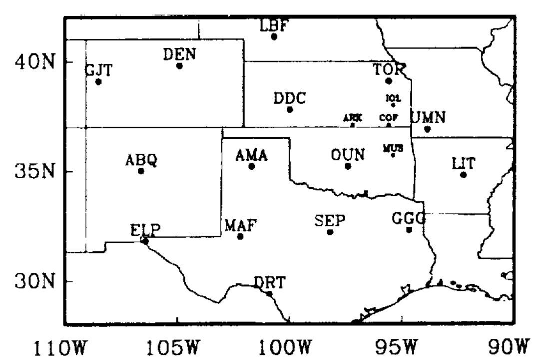

Figure 2: Map of rawinsonde stations located within the analysis region. Larger font indicates NWS stations, others are special FIRE CLASS stations.

Given the wealth of available in situ and remote sensing observations, the similarity to the FIRE Cirrus-I focal case study, and the particularly good match in scale and location of the cloud system with the rawinsonde and profiler networks, analysis of this case may yield very useful results on the life-cycle of this cirrus cloud system. We here assess the quality of the meteorological description for this case based on our preliminary analysis of the rawinsonde observations.

2 Observations

Shown in Figure 3 is the sequence of GOES infrared imagery for this case. Development and eastward propagation are evident. By mid-morning (1500 UTC), satellite imagery gives the distinct impression that there were two centers of development: one over the Texas-Oklahoma Panhandle and a second over southern Oklahoma. The latter strongly resembles a ridge-crest cirrus formation (Starr and Wylie 1990)

Figure 3: Infrared satellite imagery for 1500, 1800, 2100, and 2400 UTC on 25 November 1991.

and was distinguishable throughout the day. The fairly sharp upwind boundary of the cloud system could no longer be attributed to the effects of orographic lifting as might have been presumed based on the 1200 UTC imagery (Figure 1). Rather, this feature strongly resembled the clearing-line event described in Starr and Wylie (1990) that marked the end of the ridge-crest cirrus and preceded cirrus development associated with a trailing cold front. The satellite imagery indicates that northeastern Oklahoma, where the aircraft observations were obtained, was a region of cirrus cloud dissipation or minimal cirrus formation. Nonetheless, aircraft observations between 1700 and 1800 UTC near Tulsa indicated cloud top at about 10 km and cloud base near 6 km. Aircraft observers (M. Poellot, personal communication) described the clouds as "not dense but very diffuse" with only small crystals observed near cloud top but larger crystals (200-400 μm) at lower levels. A halo was observed. Upwind of that location, large ice crystals were also observed at about 9 km.

Rawinsonde observations from Norman (OUN) indicated a deep humid layer extending from 5 km to above 10 km at 1200 UTC with a similar situation observed at 1800 UTC (Figure 4). Tropopause height declined during the day and a noticeable lowering of the top of the humid layer was observed between 1800 on November 25 and 0000 UTC on November 26

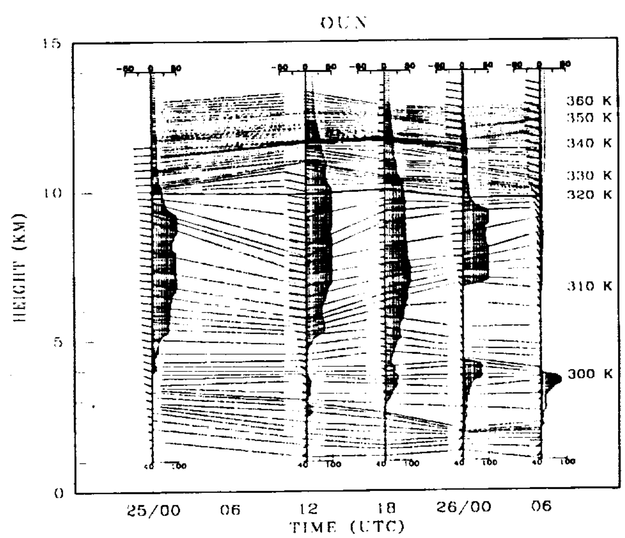

Figure 4: Time series of isentropic surfaces at 1 K intervals, percent relative humidity (shaded), and wind vectors as a function of height (km) from 0000 UTC on 25 November 1991 to 0600 UTC on 26 November 1991. The 320 K isentropic surface, which is used for analysis, is emphasized.

(from 10.5 to 9.5 km). The upper portion of this humid region of cirrus cloud formation exhibited a fairly unstable thermal stratification (*e.g.*, 8–10 km at 1200 UTC as evident by the separation of the isentropes).

An underlying stable zone, located through the lower portion of the moist layer, lifted with time. Overall, the situation resembled overrunning of an elevated warm frontal surface. Ridge passage during the midday hours was indicated by the wind field although wind directions never turned to southerly but rather swung back to northwesterly by 0600 UTC in conjunction with marked drying and clearing of the upper level clouds. We note that observations from Amarillo (AMA) indicate that northwesterly flow and dry conditions also likely existed over OUN between 0000 and 1200 UTC on 25 November (Figure 4). Observations at AMA, OUN, and Little Rock (LIT) yielded a consistent picture.

3 Meteorological Analysis

Regional analyses of the geopotential height, horizontal wind field, relative humidity (upper panel) and vertical motion (lower panel) on the 320 K isentropic surface are shown for 1200, 1800 and 0000 UTC in Figures 5–7. Relative humidity is with respect to ice for temperatures colder than -20C on all figures in this paper. It must be noted that the humidity sensor in the SDD rawinsonde used at many of south-central and southwestern NWS stations is prone to becoming "stuck" once near-ice saturation is encountered in the upper troposphere. This was an unexpected finding. Occasional observations of very high values (supersaturation) can usually be attributed to this sensor problem; nonetheless, the analyzed humidity patterns appear qualitatively correct. The vertical motions fields were derived by applying the adiabatic triangle method of Starr and Wylie (1990) to data from various combinations of NWS rawinsonde stations. Sonde drift was taken into account. The results were then objectively analized to the grid shown here. Estimated accuracy of this technique is generally about $\pm$ 2 cm sec^{-1}.

Excellent correspondence was found between features in the analyzed humidity (shaded for 80% and greater) and vertical motion fields (cross-hatched or shaded for greater than $\pm$ 2 cm sec^{-1}) and the satellite cloud observations. The shape and movement of the system was well-captured. The analyses show strong upward motion ($\sim$ 10 cm sec^{-1}) located at the upwind edge of the cirrus cloud system at 1200 UTC (Figures 1 and 5) with the region of high humidity and cloudiness exetnding eastward to the edge of the leading subsidence zone. At 1800 UTC, the region of high humidity (shaded in Figure 6) still mapped the area of cirrus cloudiness quite well (Figure 3). The analyzed vertical motion field at this time also corresponded quite well with the satellite imagery supporting our interpretation that two centers of cloud formation had developed where the strongest ($\sim$6 cm sec^{-1}) was located in southern Oklahoma and northern Texas. The analyses at 0000 UTC (Figure 7) continued to exhibit good correspondence with the satellite-observed cirrus cloud field. The system had contracted as the vertical motion weakened considerably. A small region of upward motion ($\sim$ 3 cm sec^{-1}) was analyzed at this time corresponding to the band of brightest cirrus cloudiness near Texarkansas. The band of weak upward motion extending through

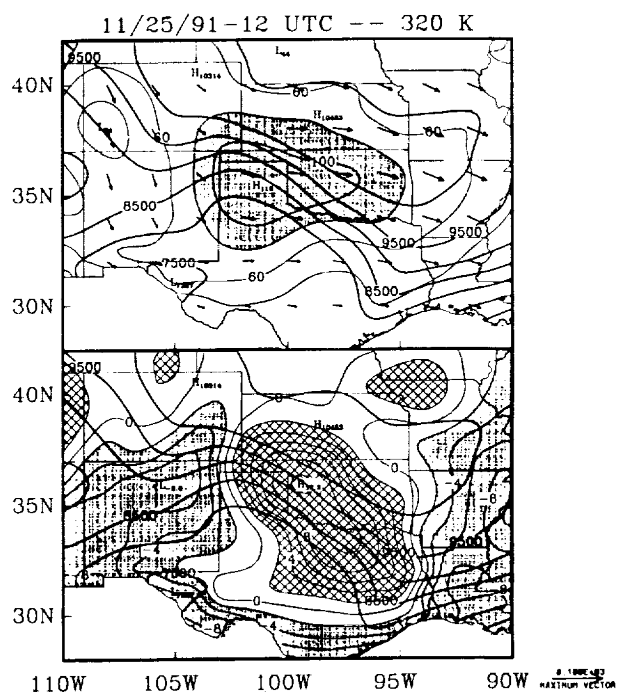

Figure 5: Analysis valid for 1200 UTC on 25 November 1991. Top diagram shows lines of constant geopotential (thick solid) at 500 m intervals, percent relative humidity with respect to ice contoured at 20% intervals (thin solid), and wind vectors for the 320 K isentropic surface. Shaded regions indicate humidity levels exceeding 80%. The bottom diagram also shows lines of constant geopotential (thick solid), as well as vertical velocity (thin solid) contoured at 2 cm sec^{-1} intervals. Hatched regions indicate upward vertical velocities greater than 2 cm sec^{-1}, while shaded regions depict downward vertical velocities exceeding 2 cm sec^{-1}.

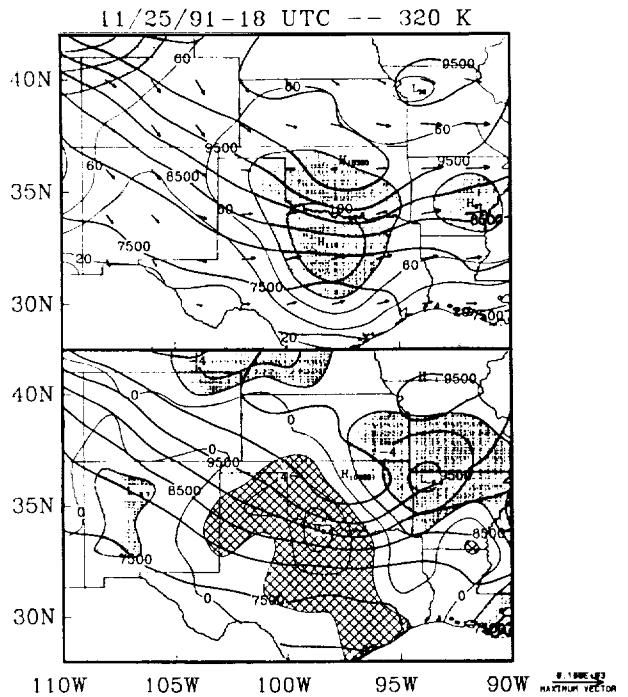

Figure 6: Same as in Figure 5 except at 1800 UTC.

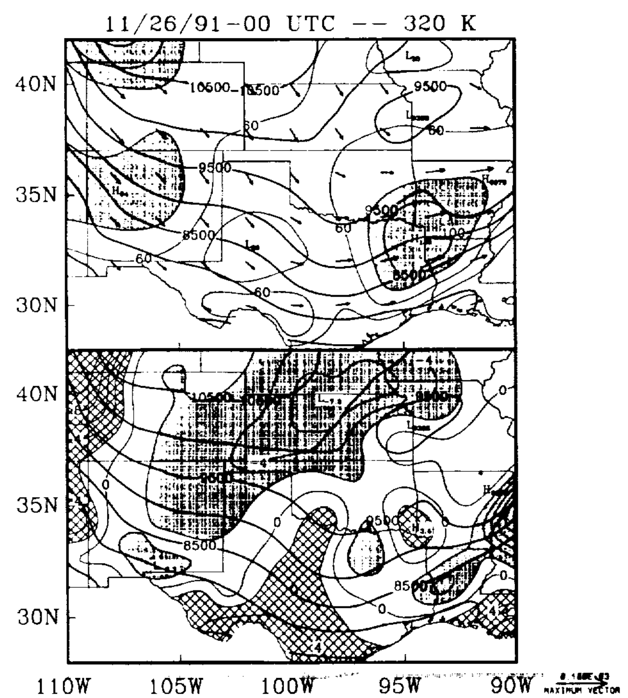

Figure 7: Same as in Figure 5 except at 2400 UTC.

central Texas may correspond to the trailing-cold-frontal zone of cirrus cloud formation seen in Starr and Wylie (1990). However, the air was too dry in the present case to allow cloud formation at this time. Such development did occur on the following day (Mace and Ackerman 1993).

4 Conclusions

Preliminary meteorological analysis of synoptic scale rawinsonde data for the 25 November 1991 FIRE Cirrus-II cirrus system over Oklahoma revealed excellent correspondence between the satellite observed cloud patterns and the observed humidity and diagnosed vertical motion patterns for this ridge-crest cirrus cloud system. The spatial and temporal evolution of this moderately-sized system appears to have been well-captured. The analyses reveal that the extensive in situ observations of cirrus cloud microphysical and radiative structure over northern Oklahoma were likley made in a region of cirrus cloud dissipation or very minimal cloud generation. Nonetheless, the similarity to the FIRE Cirrus-I focal case study and the particularly good match in scale and location of the cloud system with the rawinsonde and profiler networks indicates that further analysis of this case may yield very useful insights on the life-cycle of this cirrus cloud system. In the future, we intend to integrate our analyses with quantitative analyses of the satellite and aircraft observations and compare these results to the output of suitably initialized/forced numerical simulations of cirrus cloud life-cycle for this case.

5 Acknowledgments

The authors wish to thank Gerald Mace (Penn State University) for provıding access to the satellite imagery.

6 Reference

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